The Art of the Trade Study

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My Purpose Today

- Explain the value of a defined methodology for conducting engineering trades
- Describe a proven trade study process
- Explain how the Analytical Hierarchy Process (AHP) methodology can be applied to your trade studies

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How are your decisions typically made?

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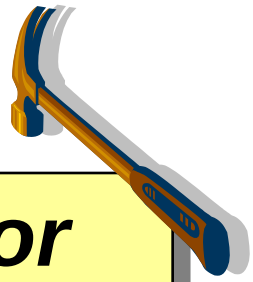


What decision aids, methods or tools do you use at GSFC?

Context

- Systems Engineers constantly define, prioritize, and decide programmatic, technical and life cycle concerns
- Proper technical decision making must balance:
  - Performance
  - Cost effectiveness
  - Schedule
  - Supportability
- The Trade Study is a core SE skill
  - Provides a repeatable, efficient method for visible, traceable, justifiable, decisions

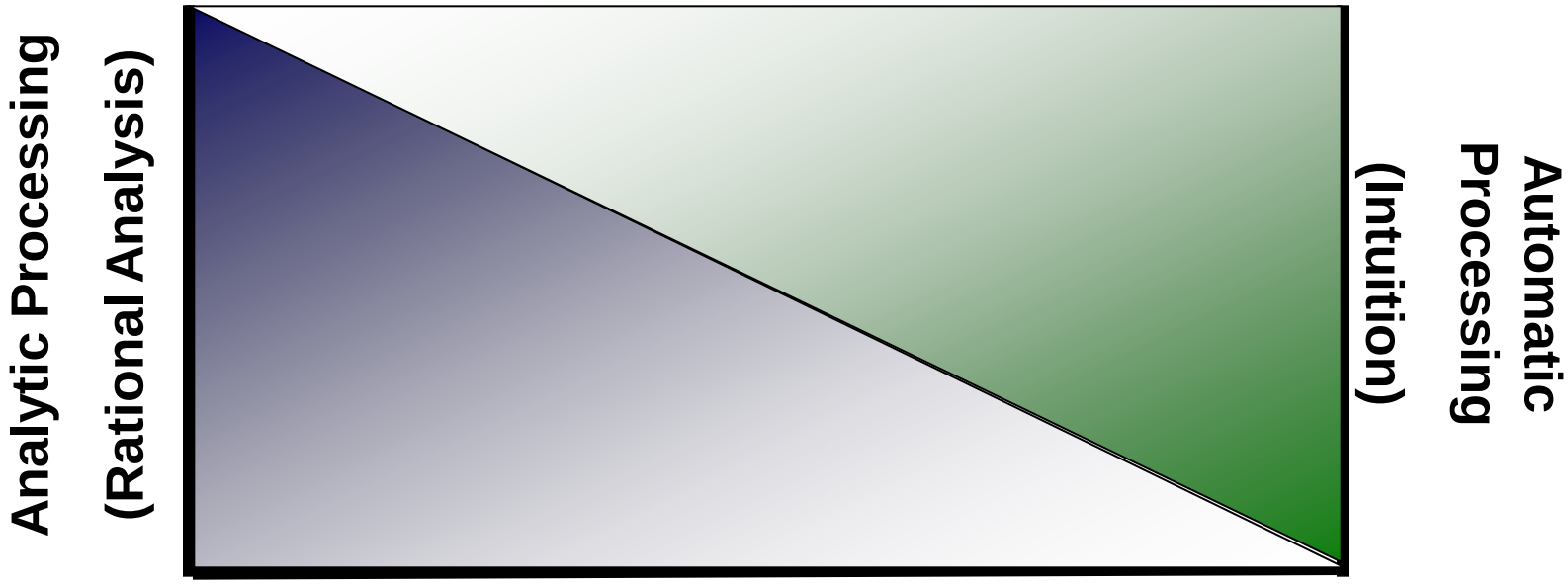
When trade studies go bad…

Real-World Trades

- How do you deal with:
  - Complexity
    - Conflicting objectives and multiple alternatives
  - Overload
    - Trying to consider numerous factors at once
  - Implicit assumptions
    - "Seat of the pants" conclusions
  - Engineering Team Buy-in
    - Decisions with lukewarm support

What obstacles to effective trade studies do you encounter on your project(s) at GSFC?

How do engineers really make decisions?



How often do you use your intuition to make engineering decisions?

The Trouble with Intuition

- **Common Cognitive Biases in Engineering Decisions**
  - Group Think
  - Status Quo Bias
  - Overconfidence Bias
  - Wishful Thinking Errors
  - Input Bias
  - Confirming Evidence Bias

Common Effects:

- Failure to critically examine all alternatives
- Tendency to continue to "do things the way we we've done them."
- Illusion of control over stochastic events
- Overestimation of probability of desired outcomes

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Intuition Test

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How does "stress" affect decision-making?

Principle of "Constancy"

Disruption of stable relations with environment is perceived as a "threat" that induces a cognitive response to reestablish stability

- Loss of constancy = stress, which triggers SNS "fight or flight"

Effects of Stress

- Occupies working memory
- Emotion tends to dominate reason
- Disrupts cognitive processes, especially complex information processing
- Encourages heuristic thinking
- Attention is focused on one or two salient cues
- Disproportionate weight ascribed to negative information
- Tendency to lock in and defend the first chosen strategy

The Case for a Consistent Trade Study Methodology

- **Provides a better *expected* outcome than random choice**
  - We can't control outcomes; the best we can do is influence the probability of certain outcomes
- **Overcome cognitive biases**
  - Mitigate negative effects of intuition
- **Permits decision traceability**
  - Allows decision process improvement
- **Builds justification and helps others understand reasoning**
  - More likely to influence up the management chain

As I think back over the years, I have been guided by four principles in decision making. First, the only certainty is that there is no certainty. Second, every decision, as a consequence, is a matter of weighing probabilities. Third, despite uncertainty we must decide and we must act. And lastly, we need to judge decisions not only the results but on how they were made.

Robert Rubin, 1999

Purpose of a Structured Trade Study

- Reach the right decision for the right reasons
  - Don't settle for just *any* decision because your team is too exhausted to argue any longer

Making tradeoffs is a fact of organizational life, especially in a resource-constrained environment. ...priorities must be determined on the basis of the enterprise's overall objectives.

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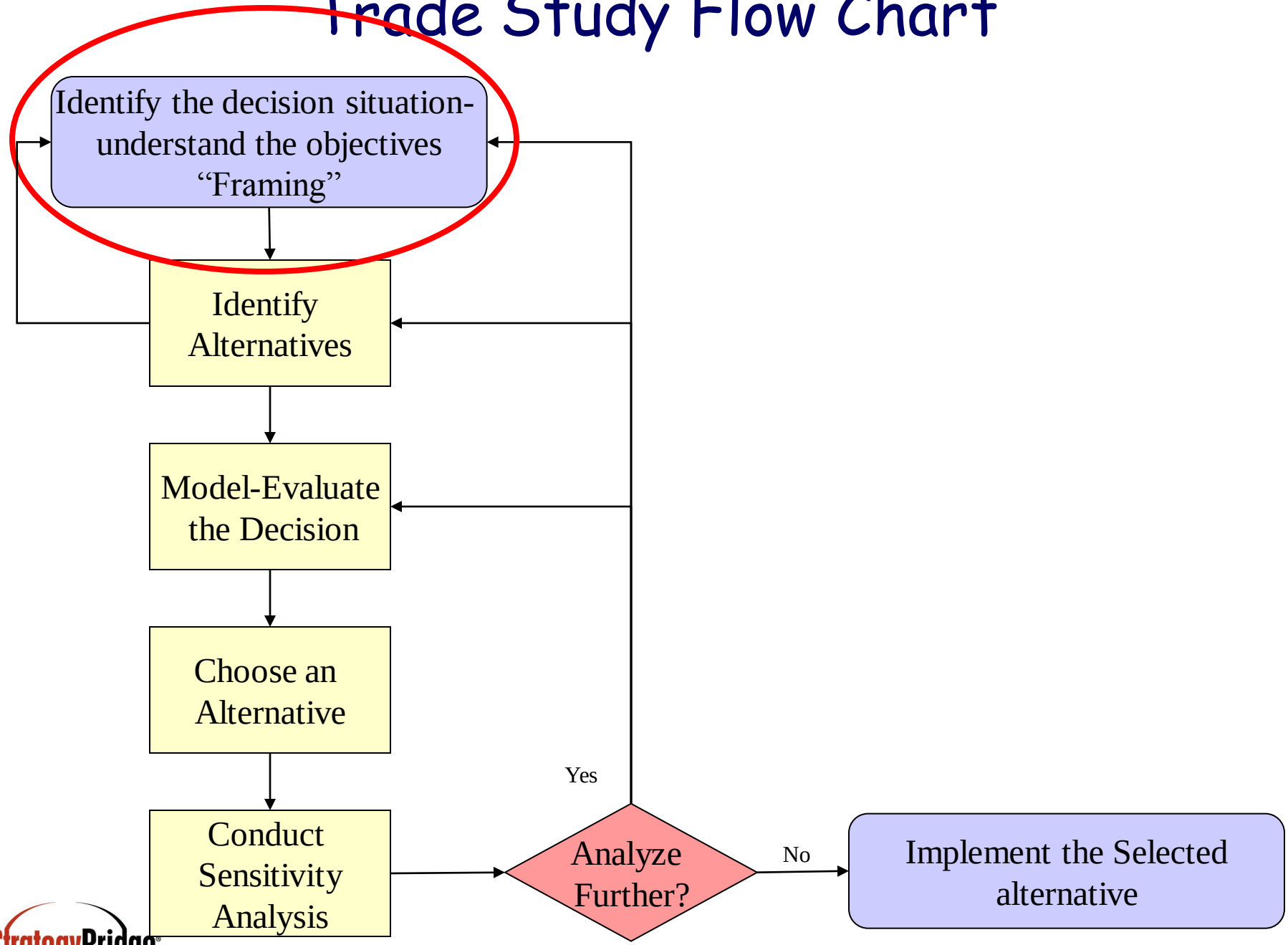
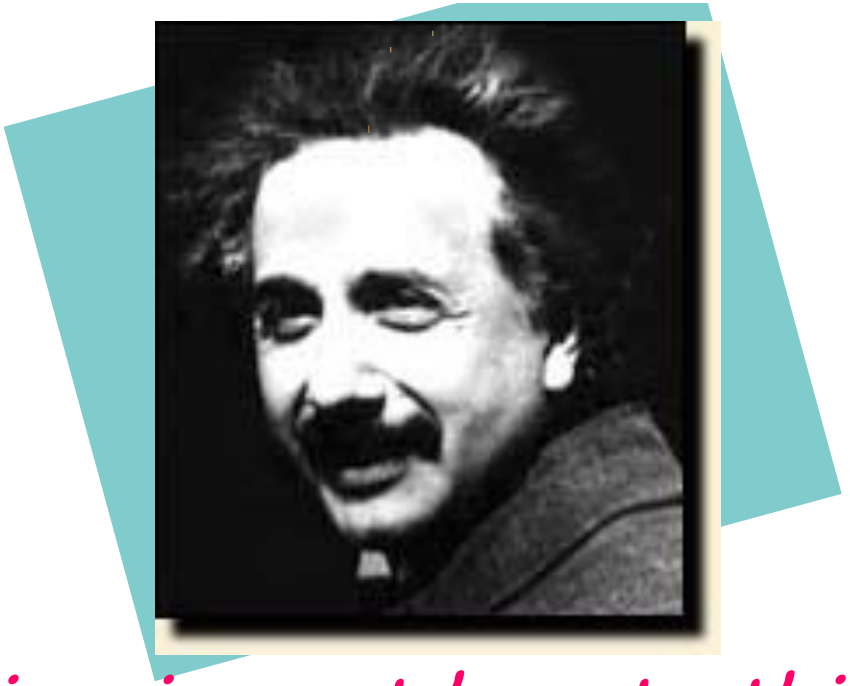
Trade Study Flow Chart



When asked what single event was most helpful in developing the theory of relativity, Albert Einstein reportedly answered:

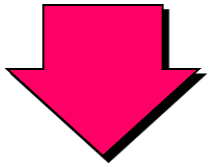


"Figuring out how to think about the problem"

The Master Decision-Making Skill:

Framing

How you define a problem will largely determine how you will go about solving it



Frame = Decision Context

Context is the set of alternatives appropriate to a specific situation

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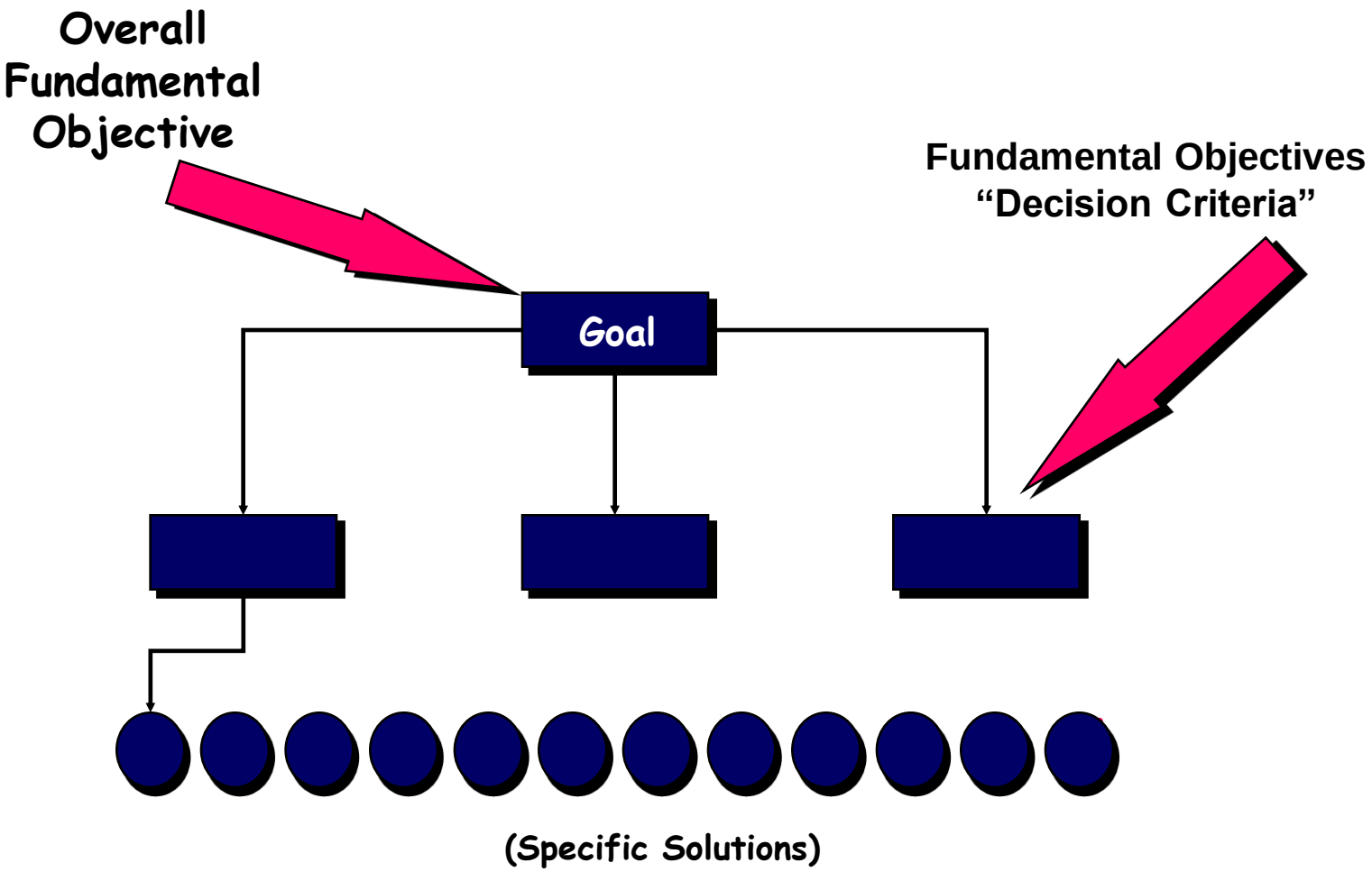
Understanding Your Frame



Helpful Questions

- What is your ultimate objective?
- What is the crux of the issue or problem?
- How does the decision affect other decisions?
- What information do we have about similar problems or decisions made previously?
- How will we implement the solution?

"There are no decision aids that can structure a problem automatically. Rather, this crucial phase must be largely achieved through unaided human judgment"

- Judgment and Choice, Robert Hogarth

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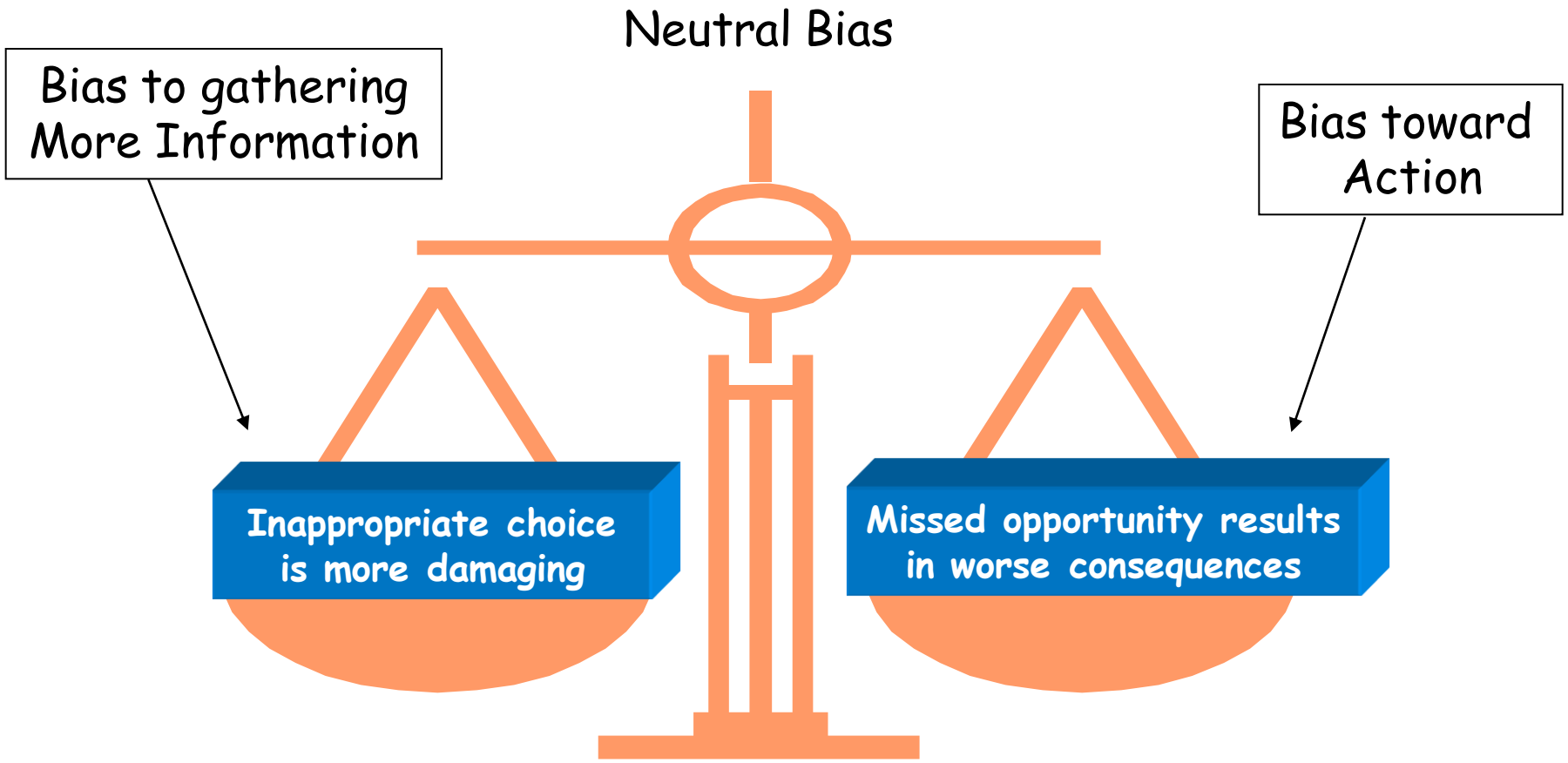
Culture and Risk Philosophy are crucial to the decision frame

- Abstract ideas that influence thinking and action in the organization
- Behaviors that are celebrated or rewarded reflect true values

Context of Implementation will Drive:

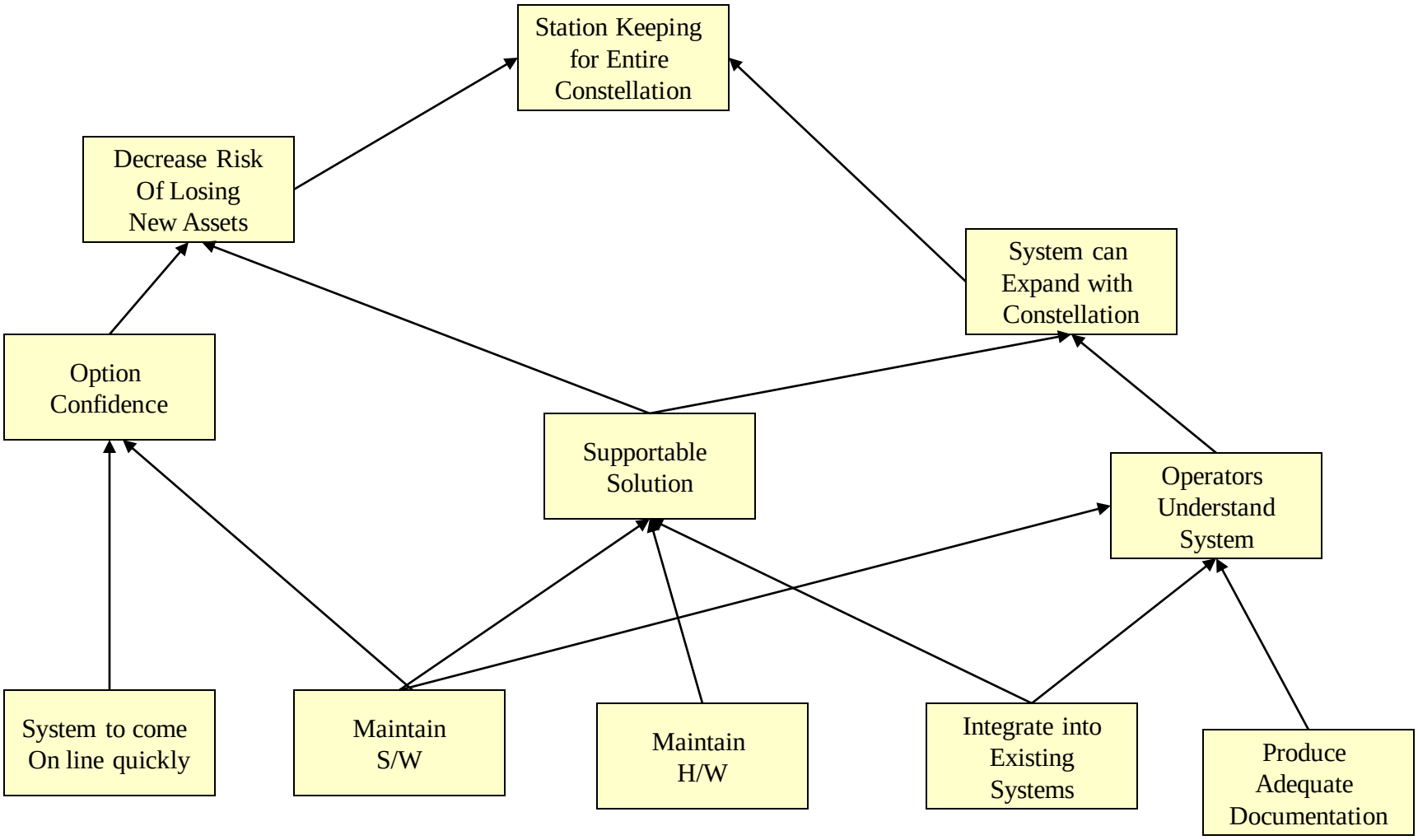
- Design
- Design Margin
- Reliability
- Quality

How does your project context affect your decision frame?

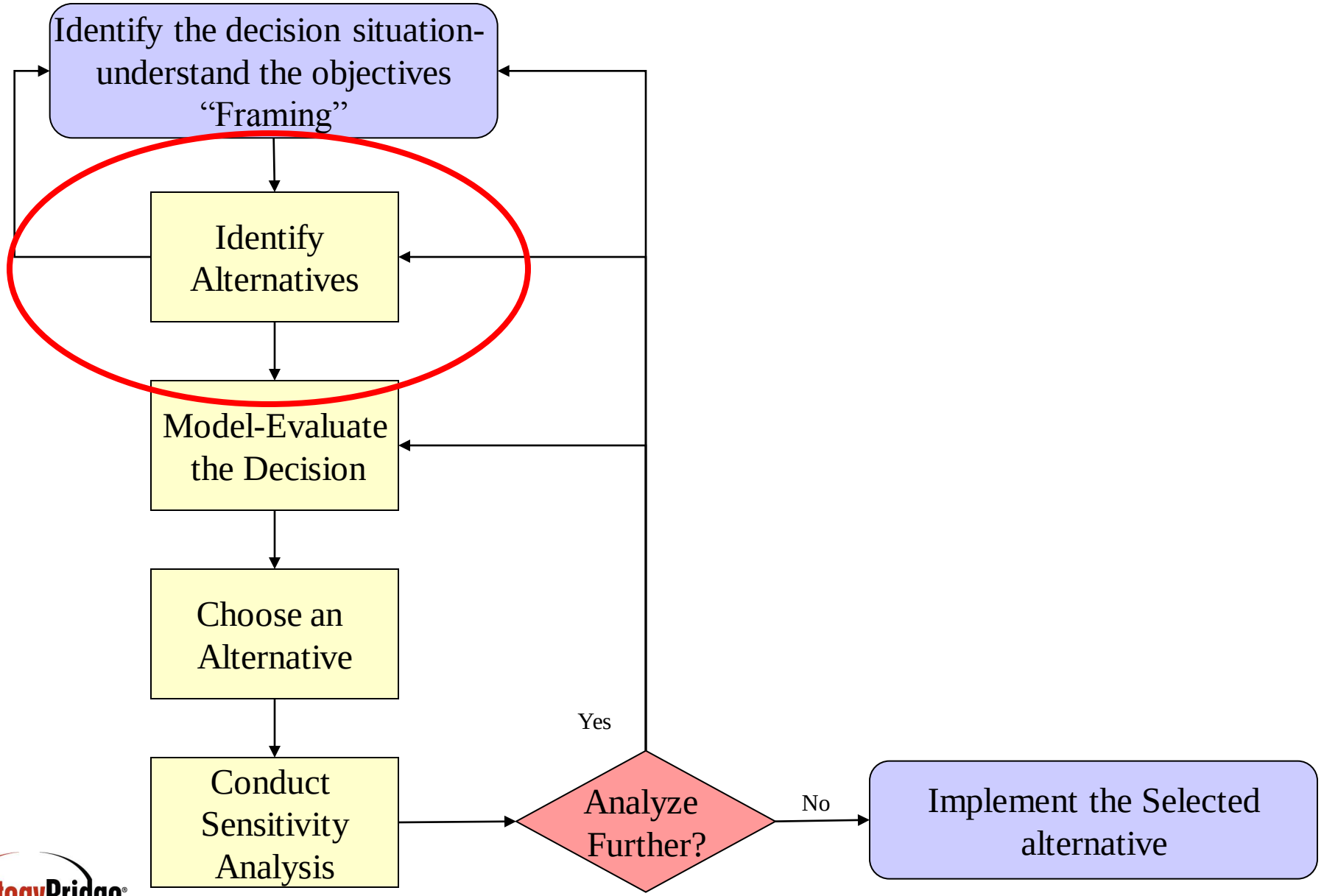


You must assess the costs of potential negative outcomes for each type of error

Technique: Means Objective Network



Trade Study Flow Chart



Generating Alternatives

"Alternatives are the raw material of decision making"

-*Smart Choices* by Hammond, Keeney & Raiffa

After the problem has been framed, ask:

"How can we obtain the desired outcome?"

- Challenge constraints – look at the problem from new angles
- Be creative, let process diverge
- Gather information, if necessary
- Withhold judgment until the evaluation phase

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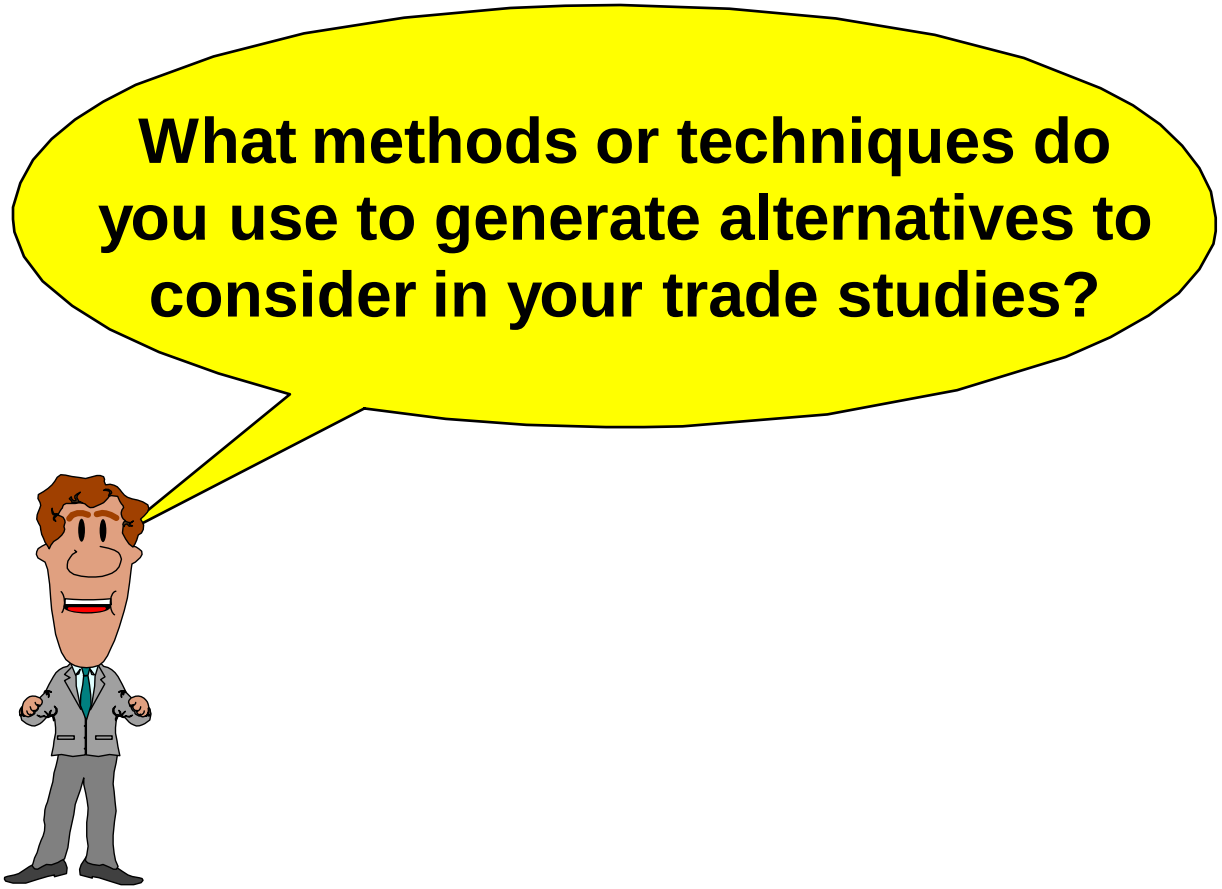
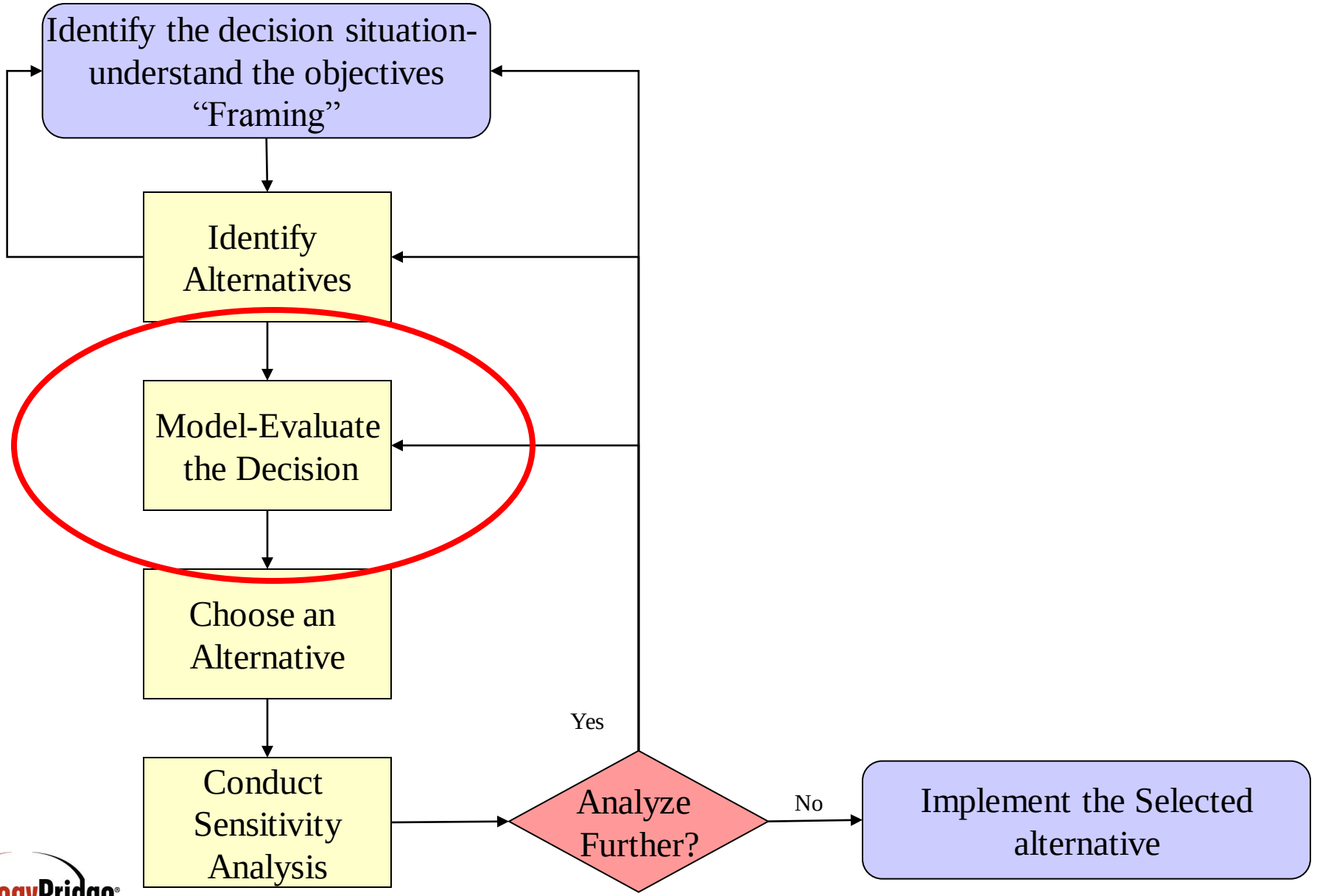


How do you ensure that you are not considering the same old alternatives while falling into a "status quo" trap?

Traps to Avoid

- Considering only a single alternative
- Considering only conventional, or "business as usual" approaches
- Looking for the "perfect" solution

Trade Study Flow Chart



Most Decision Problems are Multicriteria

- Satisfy science requirements
- Maximize design life
- Minimize lifecycle cost
- Maximize reliability
- Minimize costs of production
- Satisfy political stakeholders

Decision Criteria:

The means by which a decision-maker measures the attributes of alternatives in order to identify and assess discriminators

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How do you compare objective and subjective measures?

How do you compare things with intangible properties?

Can you compare apples to oranges?

- Taste
- Aroma
- Acidity
- Price
- ?

Question:
Do political considerations ever factor in your trade studies?

AHP Methodology in Trade Studies

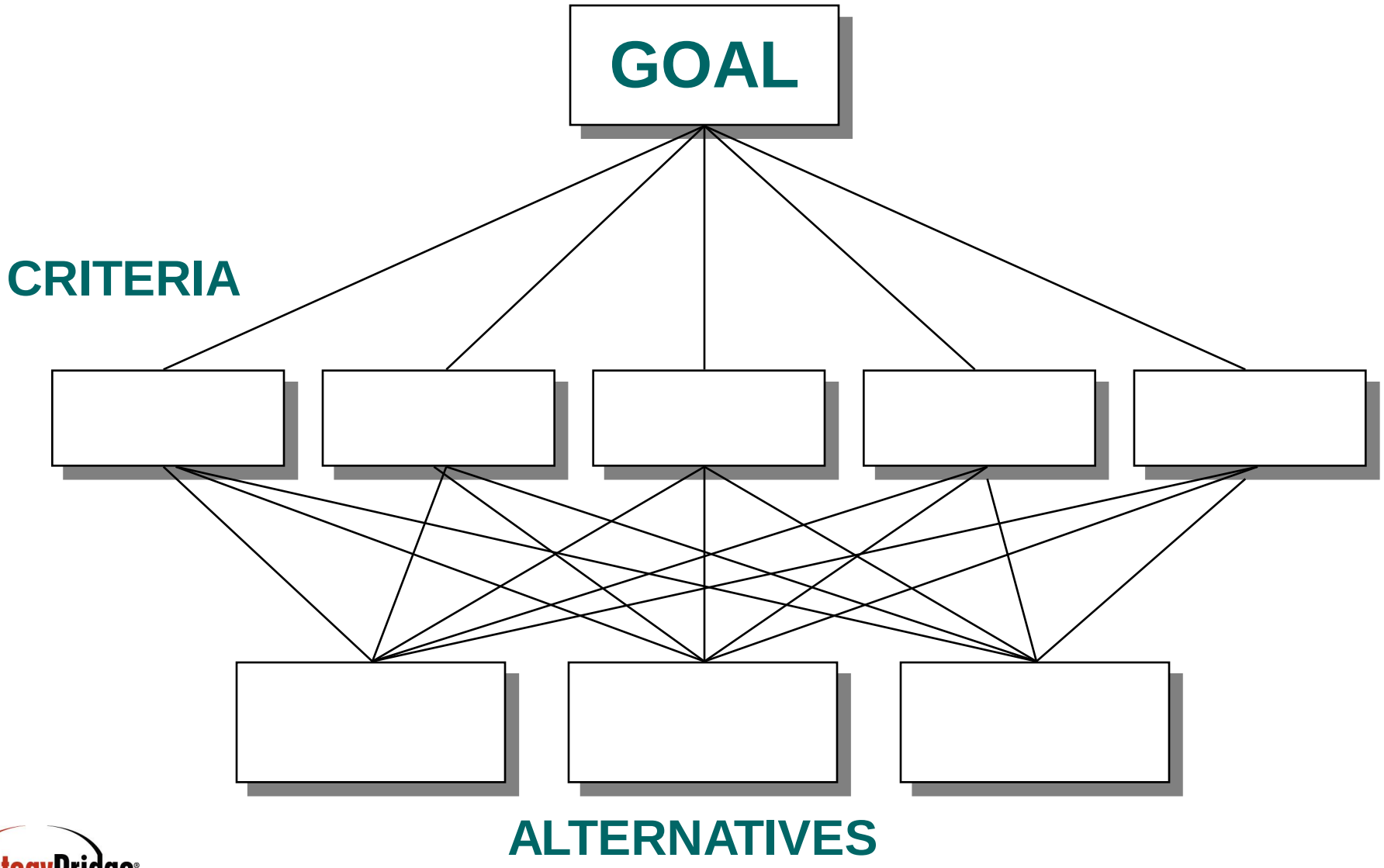
Prioritizes multiple tangible and intangible criteria:

- **In most decisions, intangibles such as**
  - political factors and
  - social factors

  take precedence over tangibles such as
  - economic factors and
  - technical factors
- It is not the precision of measurement on a particular factor that determines the validity of a decision, but the importance we attach to the factors involved
- AHP assigns importance to all the factors and synthesizes this diverse information to make the best decision

Example: *the decision to use aluminum instead of a titanium alloy for the Boeing 777 wings was not the technically preferred alternative.*

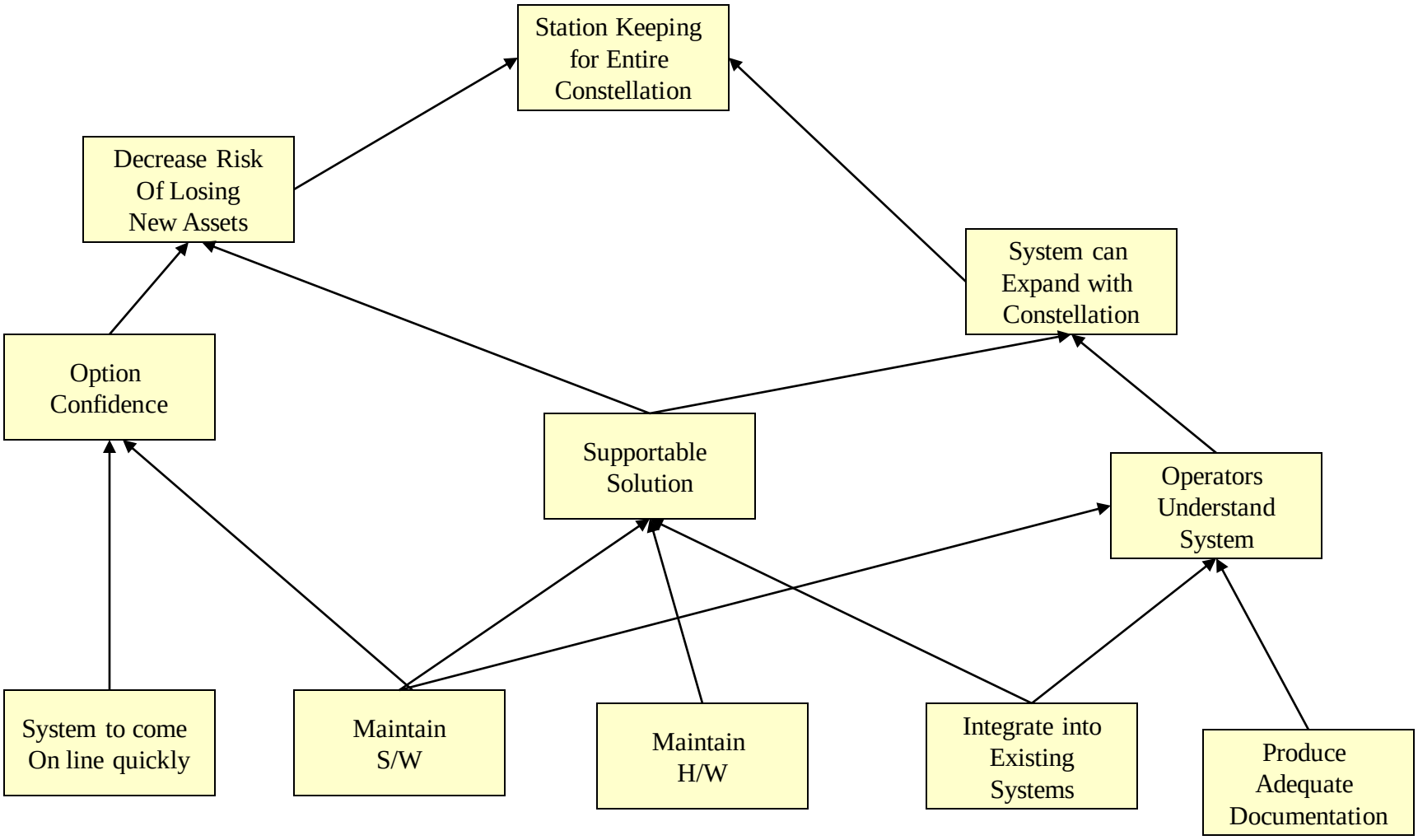
The Analytic Hierarchy Process
(Saaty- 1971)



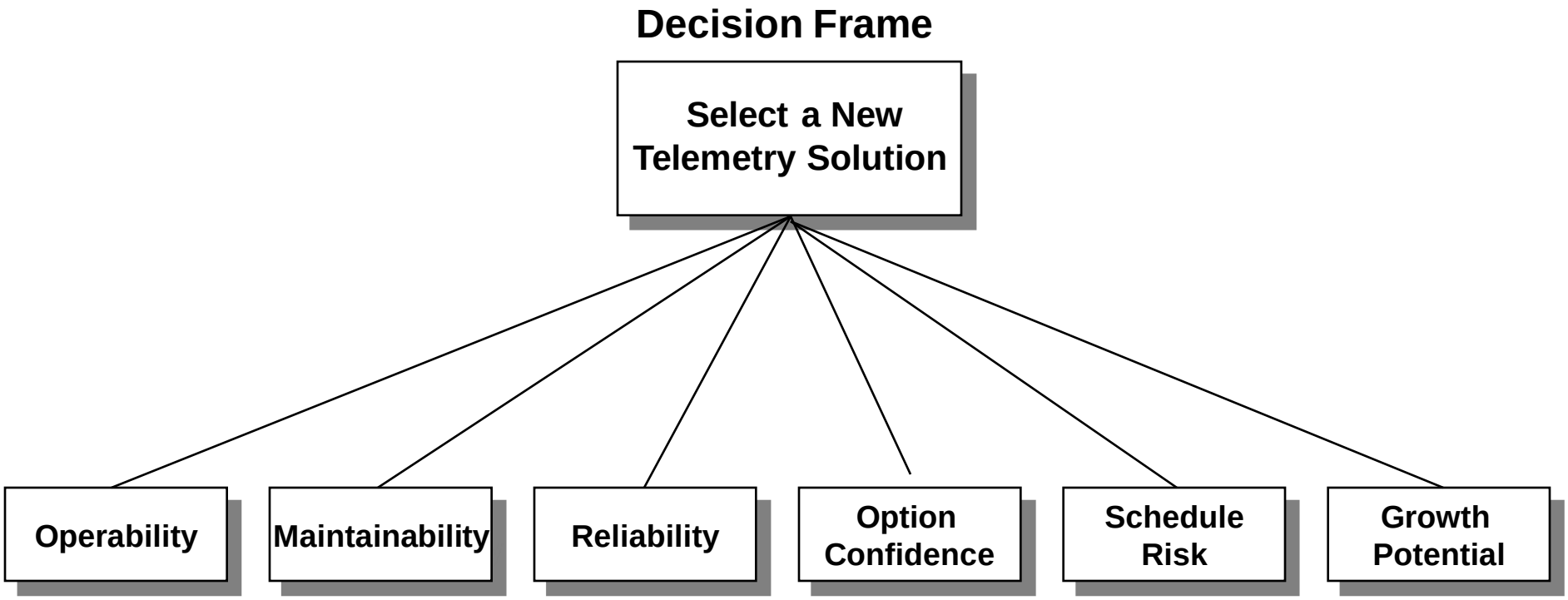
Selecting Criteria

- High quality evaluation criteria:
  - Are linked to the critical aspects of the solution
    - "Value" areas
    - Risk areas
  - Are limited to those that will yield meaningful discrimination between solutions
  - Are reasonably independent of each other

Remember Our Means Objective Network?



Establish a Fundamental Objectives Hierarchy



Choose a New Telemetry Solution for our satellite constellation

- **Operability**
  - measure of the ease with which an operator can comprehend the operating concept and operate the equipment
- **Maintainability**
  - Mean Time to Repair (MTTR)
- **Reliability**
  - Mean Time Between Failures (MTBF)
- **Option Confidence (i.e., will work as advertised)**
  - degree to which equipment will operate properly with spacecraft
  - product maturity
- **Schedule Risk**
  - risk that option can be delivered in time to meet next launch requirement
- **Growth Potential**
  - to be able to have a device which is modular and readily expandable and upgrade-able
  - capability of the design to readily accommodate technology insertion

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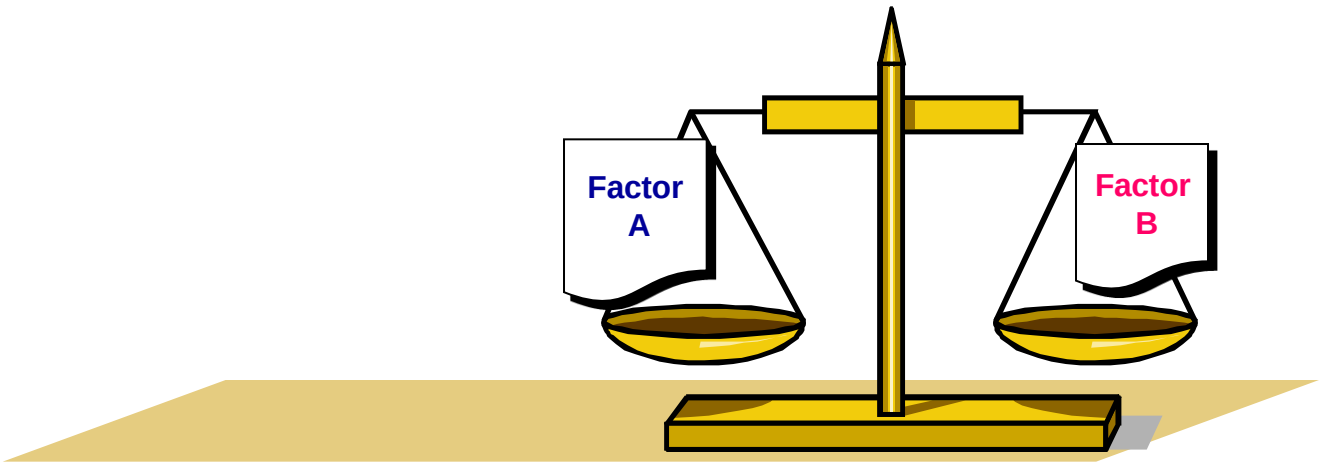
AHP Approach

- How does AHP capture human judgments?
  - AHP does not require you to make an absolute judgment or assessment.
  - Process uses relative assessment between two items at a time.
- In relative measurement a preference, judgment is expressed on each pair of elements with respect to the common "parent" element.

Simplified AHP Criteria Weighting Matrix

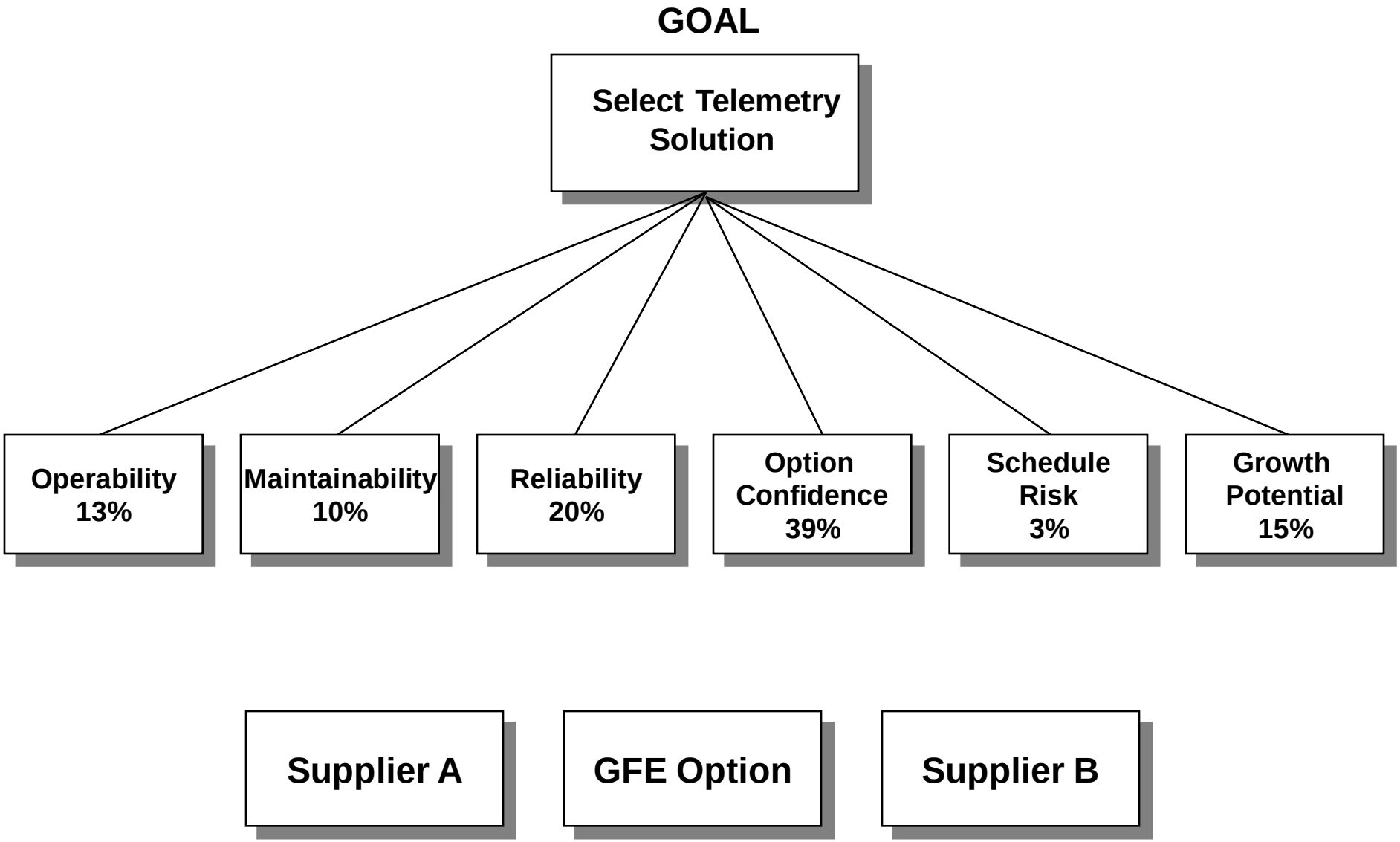
- Technique
  - Compare a list of items to one another to determine relative importance
- Uses
  - Developing criteria weights
  - Reveals high impact factors



Example
Top Level Criteria Weights

							Row Total	Weight
	Operability	**Maintainability**	**Reliability**	**Option Confidence**	**Schedule Risk**	**Growth Potential**		
Operability	1	3	3	0.2	2	0.33	9.53	13.2%
Maintainability	0.33	1	0.25	0.2	5	0.33	7.11	9.9%
Reliability	0.33	4	1	0.2	6	3	14.53	20.1%
Option Confidence	5	5	5	1	9	3	28	38.8%
Schedule Risk	0.5	0.2	0.167	0.11	1	0.33	2.307	3.2%
Growth Potential	3	3	0.33	0.33	3	1	10.66	14.8%
							72.137	
							Grand Total	

1	**Equal importance**
3	**Moderate importance of one over another**
5	**Strong or essential importance**
7	**Very strong or demonstrated importance**
9	**Extreme importance**
2,4,6,8	**Intermediate values**



Build Rating Scales

Qualitative Scale (with weights)

- Excellent = 100%
- Acceptable = 60%
- Marginal = 30%
- Not Addressed = 0%

Rating Alternatives

	Operability	Maintainability	Reliability	Option Confidence	Schedule Risk	Growth Potential	
weight	13%	10%	20%	39%	3%	15%	
Supplier A	100	60	60	60	30	100	70.3
GFE Option	100	60	100	100	60	30	84.3
Supplier B	30	100	100	30	100	60	57.6

Excellent	**100**
Acceptable	**60**
Marginal	**30**
Not Addressed	**0**

Summary of AHP Advantages

- Easy to use in trade studies
- Organizes, prioritizes and synthesizes complexity within a rational framework
- Breaks down tangible and intangible criteria into manageable components
- Fosters critical discussion and examination of implicit assumptions when used with diverse groups
  - Makes it possible to deal with conflicts in perception and in judgment

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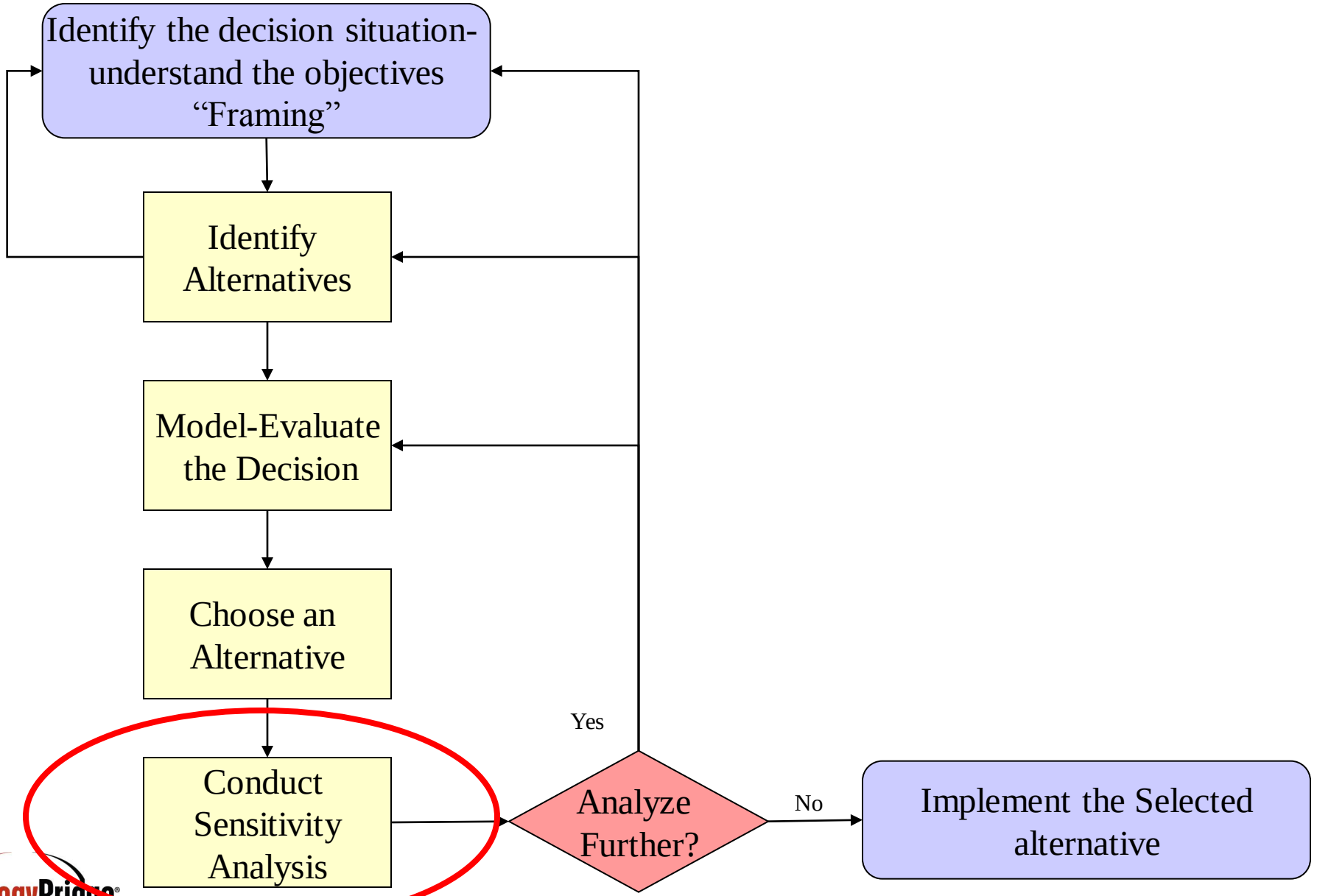
Trade Study Flow Chart

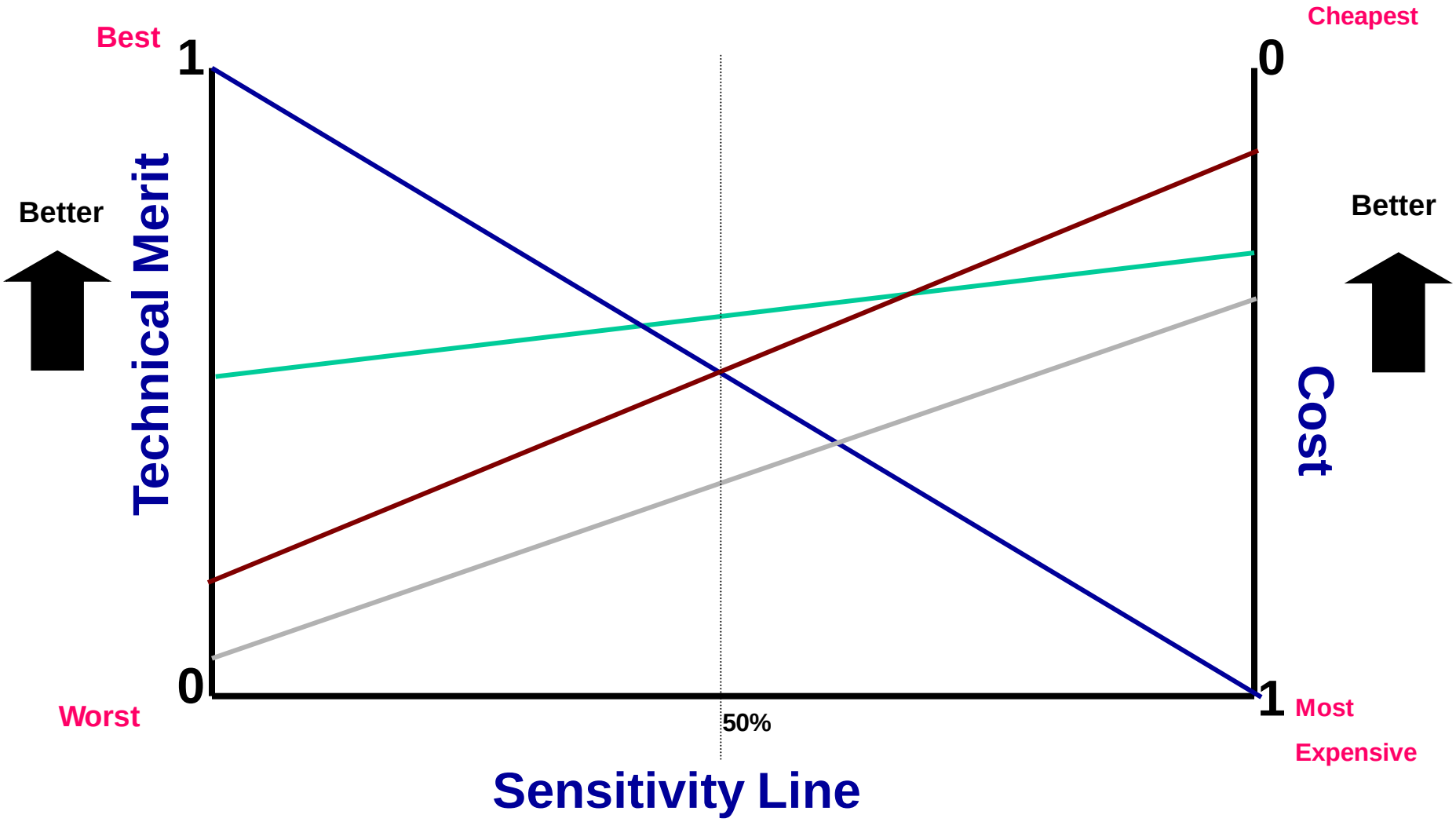


Sensitivity Analysis

- Sensitivity analysis answers the question: "What makes a difference in this decision?"
- Sensitivity analysis determines whether small changes in judgments affects the final weights and rankings of the alternatives.
  - May lead the decision-maker to reconsider the decision frame or the sufficiency of alternatives
- If so, the decision-maker may want to review the sensitive judgments.

Technique: Two-Way Sensitivity Graph

(Comparison of One Factor to Another)



Other Applications for This Methodology

Portfolio Selection
and
Resource Optimization

Why have a process for Project Portfolio Selection – Resource Optimization?

- Prioritize initiatives in a systematic way
- Optimize *overall* organizational benefit
- Meet all funding constraints
- Create a prioritized list of unfunded requirements should more budget become available

Strategy Bridge Recommended Process

- Convene the decision team with a skilled facilitator
- Agree on the fundamental objective, key business drivers, and supporting decision criteria
- Create a shared understanding of the alternatives under consideration
- Build a decision model
  - Decision Lens™ COTS software solution for group decision-making based on the Analytic Hierarchy Process
    - Provides a method for quickly synthesizing qualitative and quantitative information from multiple stakeholders for strategic trade-offs
- Facilitate a collaborative decision process and sensitivity analysis
- Document assumptions, criteria, and decision results

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Benefits

- Maximize ROI
  - Align project portfolio with organizational objectives
- Increase Decision Visibility
  - Document and examine implicit assumptions
  - Track, audit and improve decision-making over time.
- Create Decision Traceability
  - Final decision authorities can see how decisions were achieved
  - Adjust strategy to changing market conditions with dynamic sensitivity analysis
- Save Time
  - Active participation of all decision-makers minimizes the need for rework or to "sell" the decision later
  - Reduce management frustration and eliminate endless debate

Example – What do we fund this year?

- Some criteria to consider
  - Provide new services
  - Enhance customer satisfaction
  - Cost avoidance
  - Maximum ROI
  - Etc.

Summary

- **Why have a consistent trade study methodology?**
  - Overcome negative aspects inherent with intuition (cognitive biases)
  - Permit decision traceability
  - Build justification and help others understand reasoning
  - Improve your trade study process
- **Why use AHP?**
  - Does not require absolute assessments
  - Permits comparisons of tangible and intangible factors
  - Fosters rich dialog among engineering team members
  - Straight-forward and easy to use

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Questions?